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Research on the Air Conditioning Water Heater System

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ABSTRACT

The working principles and the basic features of air conditioning water heater (ACWH) system are introduced in this paper. The air conditioning water heater system can operate in five modes: water-heating only, space-cooling and water-heating, space-heating and water-heating, space-cooling, space-heating. Comparatively, the system can provide much better energy performance and higher equipment utilization throughout a year, and cause less thermal pollution than heat pump water heater and common air conditioner.

A prototype with five modes was assembled and tested at the ambient temperature from -7℃ to 43℃, especially when frosting. When it works in the water-heating mode, it can supply 55℃ hot water within two minutes, and the condensing pressure is just same with common air conditioner. When some modes switch, the temperature of the outlet hot water is constant. Theoretical analysis and experimental study were done to the ACWH in this thesis:
1. The prototype was tested in the air-conditioner laboratory of GREE. The testing data indicate that the prototype accords well with the national standards of air conditioner and heat pump water heater.
2. Based on the experimental results, analysis was done on the ACWH in main operating modes and some important conclusions were given.

The results indicate that the new system can save energy through multi-duties, and it can work stably in five work modes with high efficiency. Compared with other models, the new system also includes air-conditioning unit and water heater unit, but with fewer components and higher reliability. Based on common air conditioner, this system can offer a practicable solution coupling air conditioner and water heater. It must be changing the markets of both air conditioner and water heater.

1. INTRODUCTION

The heat pump water heater (HPWH) has been used since 1950s, mainly for household applications. It absorbs heat energy from the ambient air to acquire hot water. In the last 20 years, the study intends to design heat pump water heater with high reliability and practicability, and many manufacturers turn to offer this production based on environmental protection and energy saving. In South Africa, HPWH has penetrated 16 percent of the market share for commercial water heaters.

Because of the highly primary cost, it is difficult to become the alternative to the common water heater. However, if we can offer an air conditioner coupled with HPWH system, which can act as air conditioner and water heater with the main components such as heat exchangers, compressor, four-way valve, and capillary tube, the primary cost will be reduced and it can realize multifunction easily. In summer, with the recovery of the waste heat of condensation, it can offer “free” hot water, and also can improve the coefficient of performance (COP) of the air conditioner. When air conditioner is not required in spring and autumn, it can operate in HPWH mode. As the enhancement of the year-round utilization, it can be more efficient and is expected to become a strategy solving the air conditioning and hot water applications. Here we demonstrate an air conditioning water heater (ACWH) system, and the performance analysis is described in this article.

2. THE PRINCIPLE OF ACWH

The schematic diagram of air conditioning water heater system is shown in Figure 1. The system can offer the following five operating modes. Mode 1 is only for heating water; mode 2 can act as space-cooling and water-heating; mode 3 can realize both space-heating and water-heating; the other two modes are the same with the common air-conditioning circles. The switching among all these modes is by means of on-off controls of the solenoid valves and four-way valve. Each mode will be demonstrated as follows.

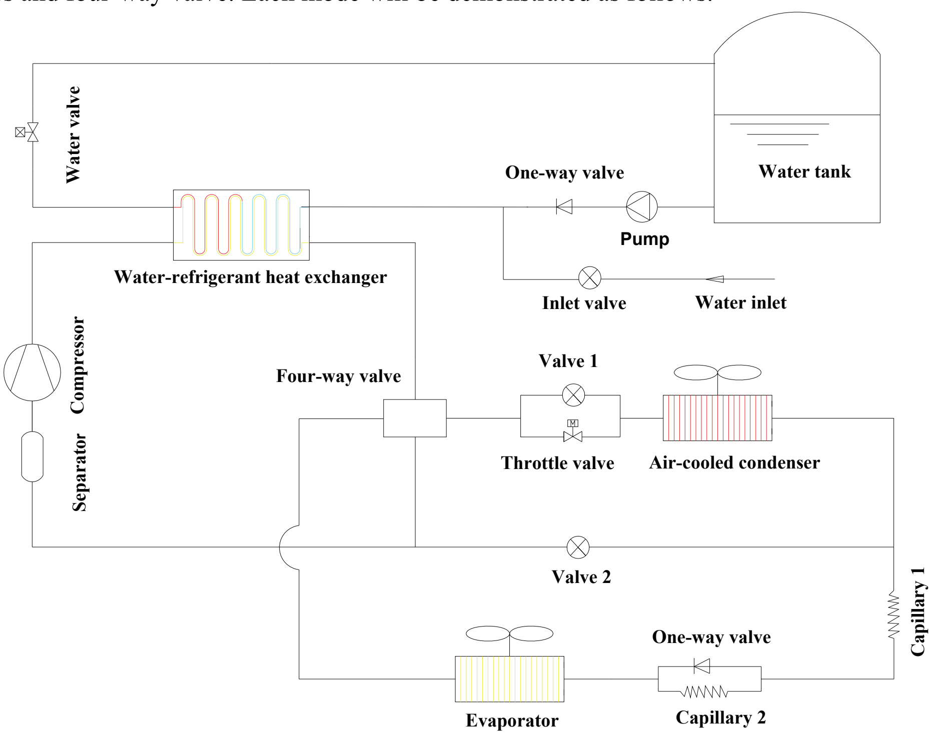

Figure 1: The schematic diagram of air conditioning water heater system

2.1 Water Heating Mode

The system can operate in two heating modes. The one is direct heating water; the other is heating water with water recycle in the adiabatic water tank. The controller can adjust the operating mode according to the water level sensors in the tank. A water valve is placed at the hot water outlet which can be adjusted to control the water flow and keep the condensing pressure constant. When the tap water goes into the water-refrigerant heat exchanger (WRHE), it will be heated to 50-55℃ directly within two minutes. If needed, the outlet water temperature can be set by adjusting the water valve.

As shown in Figure 1, when the power is on, the compressor sucks low-pressure refrigerant gas and then discharges high-pressure gas into water-refrigerant heat exchanger (WRHE), where refrigerant is condensed and water is heated directly. After heat exchanges, the liquid refrigerant flows across four-way valve, then it is throttled to low-temperature and low-pressure liquid and gas by an electronic expansion valve. Refrigerant flows into outdoor air-cooled condenser where it is evaporated and becomes low-pressure gas. When the low-pressure gas returns to the compressor, the circle begins again. In this mode, valve 1 is closed and valve 2 is open. When heating water, the outdoor air-cooled unit acts as evaporator, and the indoor fan doesn't run. The COP_w is presented as a function of power Q_w and the electric power W as shown in Equation (1).

$$COP_w=Q_w / W=MC\triangle T \qquad (1)$$

Where M is the mass flow of water; C is the specific heat of water; $\triangle T$ is the water temperature difference between outlet and inlet of the water-refrigerant heat exchanger (WRHE).

2.2 Space-cooling and Water-heating (SCWH) Mode
In summer, with the recovery of condensing heat, the indoor air is cooled down at the same time. Compared with water-heating mode, the high-temperature refrigerant is also condensed in the WRHE directly, and then goes through the air-cooled condenser to be super-cooled where the outdoor fan doesn't run. It is throttled by capillary 1 to low-temperature liquid and gas, and the indoor air exchanges heat with returned refrigerant. In this mode, valve 1 is open and valve 2 is closed. This mode can act as space cooling and water heating at the same time. However, it is not necessary to recover the entire condensing heat which can be released in the air-cooled condenser. The total capacity is the sum of cooling capacity Q_c and heating capacity Q_w, and then total COP_{cw} can be shown as the Equation (2).

$$COP_{cw}=(Q_c+Q_w)/W \tag{2}$$

2.3 Space-heating and Water-heating Mode
Refrigerant flows across WRHE, evaporator, capillary 2, capillary1, and air-cooled condenser in turn. Space-heating and Water-heating can realize in theory. This mode sometimes may not meet customers' expectations, so that it must operate combined with the water-heating mode and spacing-heating mode. If needed, an electric heater is available.

2.4 Space-cooling Mode and Space-heating Mode
In these two modes, refrigerant doesn't flow across WRHE or the water pump and inlet valve are closed, and the condensing heat is completely released by the outdoor or indoor heat exchanger. In fact, it is the same with a normal air conditioner, and is not described any more as above. In summer, space-cooling mode can be replaced by the SCWH mode, which can use the water-cooled and air-cooled heat exchangers at the same time. The performance of the system will be improved significantly with the enhancement of heat transfer.

3. EXPERIMENTS

Experimental research was performed at an air-enthalpy test laboratory which can also supply water with required temperature and mass flow. The laboratory includes outdoor chamber, indoor chamber and control room. It consists of insulated walls, air-handling equipments, temperature and humidity collection system, air volume testing equipment, electric control system and computer handling unit. The cooling and heating capacity can be tested by air-enthalpy test. Air handling equipments are provided in both test chambers to control the dry bulb and wet bulb temperatures, as well as humidity. The indoor unit of air conditioning was placed in one chamber; the outdoor unit and adiabatic storage tank were placed in another chamber. T-type thermocouples were placed at each temperature test point and pressures were tested by the pressure sensors. All the testing data can be collected and displayed by the computer handling system.

Table 1: Experimental test conditions in this study

Operating Modes		Outdoor chamber, ℃	Indoor chamber, ℃	Inlet/outlet water temperature,℃
		Dry/wet bulb temperature	Dry/wet bulb temperature	
Mode 1	Water-heating only	-7~43/-	20/15	9~30/55
Mode 2	Space-cooling and water-heating	35/24	27/19	15/55
Mode 3	Space-heating and water heating	7/6	20/15	9/55
Mode 4	Space-cooling	35/24	27/19	-
Mode 5	Space-heating	7/6	20/15	-

3.1 Prototype Design
The prototype includes outdoor unit, indoor unit, and an adiabatic storage tank. Based on a common air conditioner, the system adds a water-refrigerant heater exchanger, a storage tank, several solenoid valves, and water pump. The

storage tank is an insulated cylinder and water capacity is about 800L. The prototype was designed based on the schematic diagram shown in Figure 1.

3.2 Experimental Test Conditions

In mode 1, the ambient temperature was from -7℃ to 43℃, and the inflow water temperature was from 9℃ to 30℃. The outlet water temperature was set to 55℃ by adjusting the water valve. The other four modes operated only in the nominal test conditions according to the national standards of air conditioner and heat pump water heater. The experimental test conditions are shown in Table 1.

4. RESULTS

This study emphasizes on the direct heating water. Mode 1 was tested in temperature conditions, while mode 2 just operated in the standard testing condition shown in table 1. The prototype is different from a common heat pump water heater, which can offer hot water within 2 minutes by means of heat transfer of large temperature difference. The experimental results were discussed combined with the first two modes as follows.

4.1 Hot Water Output

The curves of hot water output are shown in Figure 2 at different inflow water and ambient temperatures. As shown in Figure 2, the hot water output tends to rise more rapidly at higher ambient temperature or inflow water temperature. It can offer about 400L hot water each hour when the inflow water temperature is 15℃ and ambient temperature is 20℃. From this figure, we can know that the hot water output is relative to the parameters of the inflow water and ambient air. When the ambient temperature is 30℃ and the inflow water temperature is 40℃, the hot water output is about 800L, while it decreases sharply to 120L at -7℃ ambient temperature and 5℃ inflow water temperate. The mass flow is also various in different conditions, so that the hot water output changes accordingly. Therefore, we should choose the equipment according to the largest hot water consumption in cold weather.

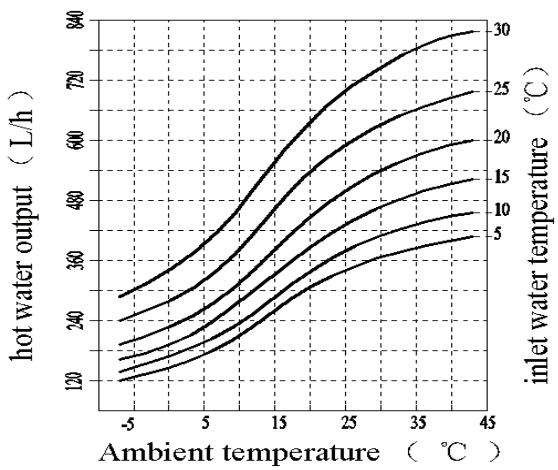

Figure 2: Hot water output vs. inflow water and ambient temperatures

4.2 Variation of System Parameters

Experimental results at variable inflow water and ambient temperatures are shown in Figure 3-6. As shown in Figure 3, the increase of inflow water temperature causes that the heating power increases a little, and the heating capacity decreases about 100~200W, so the COP_w decreases. Compared with Figure 3, Figure 4 shows that as the ambient temperature rises, the heating capacity increases significantly, but the power consumption does not increase greatly. Therefore, the COP_w increases.

Figure 5 shows that as inflow water temperature rises, the outlet water temperature, the discharge temperature and outlet refrigerant temperature of WRHE do not increase significantly, and the inlet refrigerant temperature keeps constant at first and then decreases obviously. As seen in Figure 6, because the outlet water temperature is constant, the condensing pressure is almost stable at about 2.1 MPa, while the evaporating pressure increases with the rise of ambient temperature.

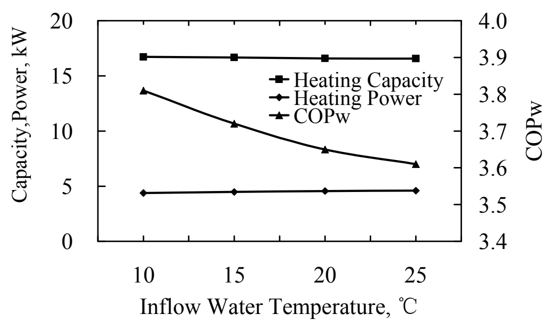

Figure 3: Heating capacity, power and COPw vs. inflow water temperature

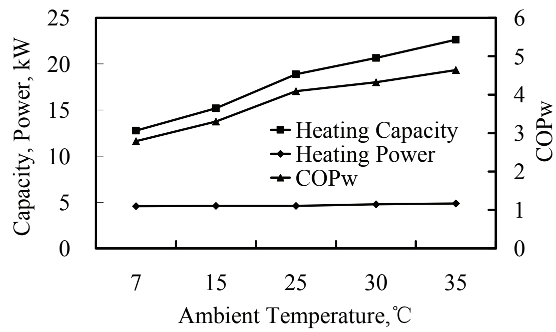

Figure 4: Heating capacity, power and COPw vs. ambient temperature

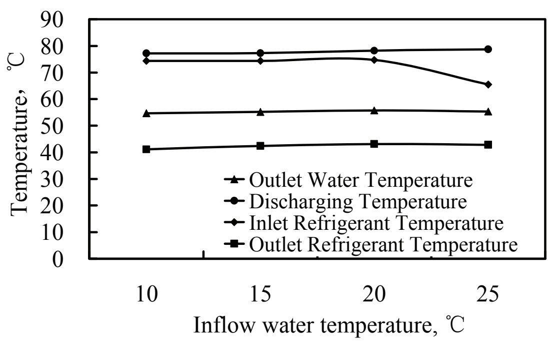

Figure 5: Experimental results of variable inflow water temperature

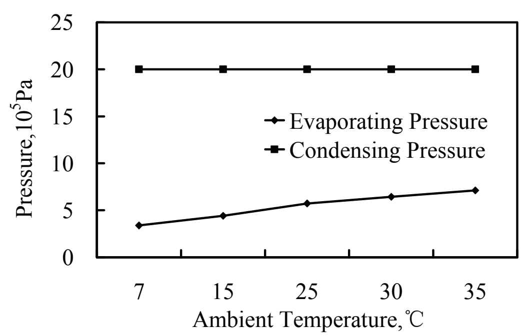

Figure 6: Pressure vs. ambient temperature

In mode 2, when the indoor air temperature is cooled down, and the condensing temperature is constant, the compression ratio will increase gradually even to be overloaded, especially in cold weather. For the sake of stability and safety, it is necessary to restrict the compression ratio. When the room temperature meets the limited value, the system will switch to water-heating mode, and the evaporator turns to outdoor air-cooled heat exchanger, so that the compression ratio can be controlled during the operation period in water-heating mode. Generally, when pipe temperature is below -2℃ in the indoor unit, the freezing protection will be effective, and the indoor fan doesn't run any more. Then the compression ratio decreases, and the evaporating pressure rises obviously. In cold weather, the compression ratio in mode 1 also increases gradually because of frosting, so it is important to defrost in time, which makes the discharging temperature and evaporating pressure under control.

4.3 Heating Water of Large Temperature Difference

In Figure 7, the results of measured temperatures in the characteristic process points are presented. During operation of the system, the inlet refrigerant temperature ($T_{r,i}$) was 76°C, and the condensing temperature (T_k) was about 53°C. The outlet Refrigerant temperature of WRHE ($T_{r,o}$) was kept constant to 42 °C. The degree of super-cooled was no less than 10 °C. When inflow water temperature ($T_{w,i}$) is 15°C, the outlet water temperature ($T_{w,o}$) can reach 55°C. By means of heat transfer of large temperature difference, sensible heating effect is remarkable. As the flow decreases, it is easy to realize high outlet water temperature even above the condensing temperature. For the HPWH adopting recycle heating water mode, as the inflow water temperature increases gradually, the COP_w and heating capacity decrease sharply, and the system will be easy to be overloaded. However, for this direct water-heating mode, maximum discharging pressure is just about 2.1MPa, which is well within the safe compressor operating range.

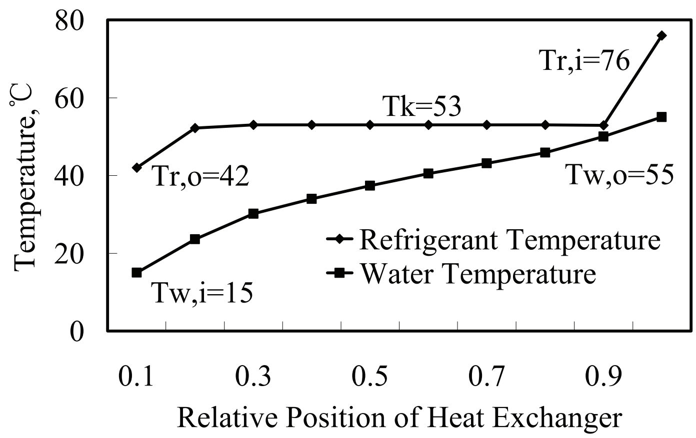

Figure 7: Temperatures in the characteristic process points, 20℃ ambient temperature in mode 1

4.4 Coefficient of Performance

Figure 8 shows that the COP_w of water-heating mode is from 1.8 to 5.5 at different ambient temperatures. As the ambient temperature rises, the COP_w also increases. When the ambient temperature is -7℃, the water heating COP_w is about 1.8. In mode 2, total COP_{cw} is the sum of COP_w and COP_c. The heating and cooling capacities are 29743W and 12198W, respectively, and the total COP_{cw} of this system is about 6.8. The COPw of heating water is above 4.0, and the COP_c reaches 2.8, which is expected to be higher when the outlet hot water temperature is lower than 55℃. When the indoor air temperature drops, the total COP_{cw} also decreases. Then it turns to the water-heating mode, and the overcharged refrigerant will be removed to operate at optimal heating water cycle. On the other hand, when the water in the tank meets the limited water level, the outdoor fan runs and the condensing heat is dispersed by the air-cooled heat exchanger. All these indicate that the air conditioning water heater system can operate with high efficiency and save energy even at low ambient temperature.

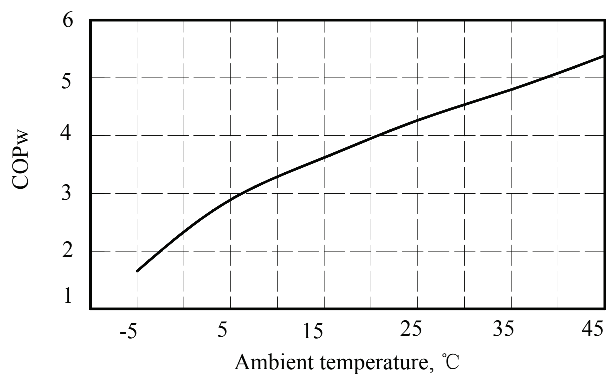

Figure 8: Curve of water-heating mode

5. CONCLUSIONS

According to the experimental results, the air conditioning water heater system can operate in five modes, and it can replace air conditioner and water heater. In HPWH mode, cold water can be heated to 55℃ directly which is well within the safe operating range. Compared with the traditional air conditioner and water heater, the prototype can supply hot water in time, and it improves the system's all-year utilization. The highest COP_w in water-heating mode is 5.5, and the nominal COP_{cw} is 6.8 in mode 2, which is expected to be higher for this prototype based an air conditioner with higher COP. The ACWH provides an ideal strategy solving the hot-water supply and air-conditioning at the same time. The results indicate that the new system can save energy through multi-duties, and it can work stably in several work modes with high efficiency.

NOMENCLATURE

COP	coefficient of performance	(–)	**Subscripts**	
ACWH	air conditioning water heater	(–)	c	cooling
W	power consumption	(W)	r	refrigerant
C	specific heat	(kJ/kg.℃)	k	condensing
Q	heat-flow rate	(W)	w	water
T	temperature	(℃)	i	inlet
M	mass flow	(kg/h)	o	outlet

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